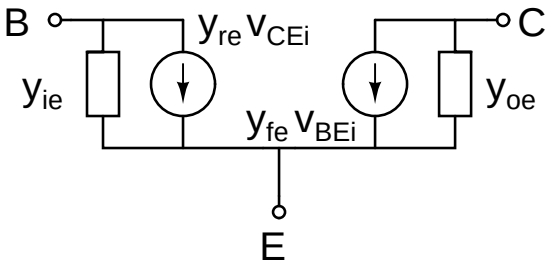
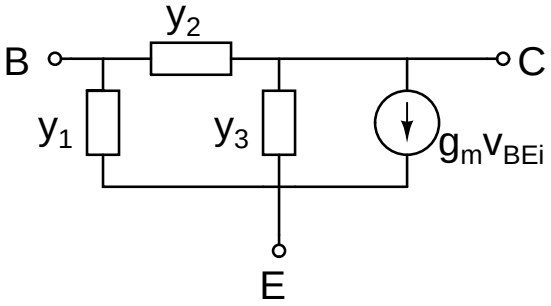
ANALOG CIRCUITS : PROBLEM SET 4

shanthi@ee.iitm.ac.in

1 Problem 1

The following two circuits are incremental equivalents of a common emitter transistor for a small signal operation around a Q-point.





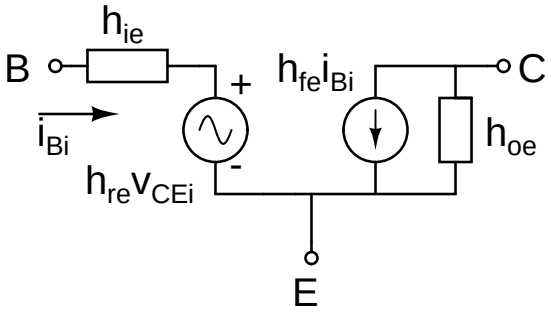
Determine y_1, y_2, y_3, in terms of y_{ie}, y_{re}, y_{fe}, y_{oe} and hence in terms of the common emitter h-parameters.

1.1 ANSWERS :

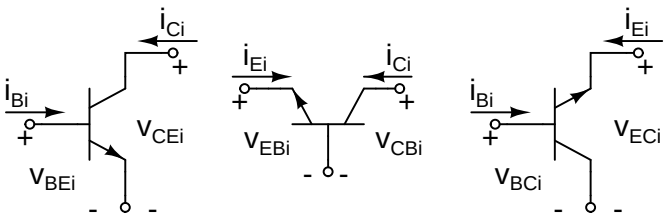
$$
\begin{aligned}
y_1 &= y_{ie} + y_{re} = \frac{1 - h_{re}}{h_{ie}} \\
y_2 &= -y_{re} = \frac{h_{re}}{h_{ie}} \\
y_3 &= y_{oe} + y_{re} = h_{oe} - (1 + h_{fe})\frac{h_{re}}{h_{ie}} \\
g_m &= y_{fe} - y_{re} = \frac{h_{fe} + h_{re}}{h_{ie}}
\end{aligned}
$$

2 Problem 3

Voltages and currents are both time varying small increments for the following circuit.



The h-parameter equivalent circuit can also be used to represent common collector and common base transistors for linear small signal operation about a Q-point. Calculate the CC and CB h-parameters in terms of CE h-parameters.



Common Emitter(CE) h-parameters

$$
\begin{aligned}
v_{BEi} &= h_{ie} i_{Bi} + h_{re} v_{CEi} \\
i_{Ci} &= h_{fe} i_{Bi} + h_{oe} v_{CEi}
\end{aligned}
$$

Common Base(CB) h-parameters

$$
\begin{aligned}
v_{EBi} &= h_{ib} i_{Ei} + h_{rb} v_{CBi} \\
i_{Ci} &= h_{fb} i_{Ei} + h_{ob} v_{CBi}
\end{aligned}
$$

Common Collector(CC) h-parameters

$$
\begin{aligned}
v_{BCi} &= h_{ic} i_{Bi} + h_{rc} v_{ECi} \\
i_{Ei} &= h_{fc} i_{Bi} + h_{oc} v_{ECi}
\end{aligned}
$$

The quatities marked are small signal increments around a Q-point in the active region. The equations are linear small signal relationships.

2.1 ANSWERS :

CC parameters :

$$\begin{aligned} h_{ic} = h_{ie} \quad h_{rc} &= 1 - h_{re} \\ h_{oc} = h_{oe} \quad h_{fc} &= -(1 + h_{fe}) \end{aligned}$$

CB parameters:

$$\begin{aligned} h_{ib} &= \frac{h_{ie}/(1+h_{fe})}{1 - h_{re} + \frac{h_{ie}h_{oe}}{1+h_{fe}}} \\ h_{rb} &= \frac{\frac{h_{ie}h_{oe}}{1+h_{fe}} - h_{re}}{1 - h_{re} + \frac{h_{ie}h_{oe}}{1+h_{fe}}} \\ h_{fb} &= \frac{-h_{fe}}{(1+h_{fe})} - \frac{h_{oe}h_{ie}/(1+h_{fe})^2}{1 - h_{re} + \frac{h_{ie}h_{oe}}{1+h_{fe}}} \\ h_{ob} &= \frac{h_{oe}/(1+h_{fe})}{1 - h_{re} + \frac{h_{ie}h_{oe}}{1+h_{fe}}} \end{aligned}$$

3 Problem 4

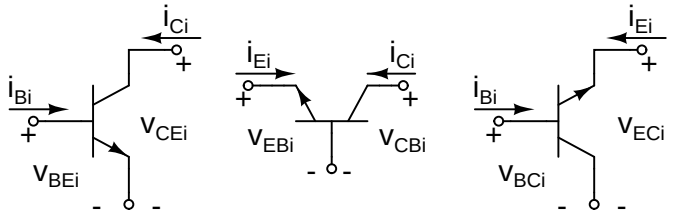
Calculate the CC and CB h-parameters. The CE h-parameters are : $h_{ie} = 4000\Omega$; $h_{re} = 0$; $h_{fe} = 200$; $h_{fe} = 200\mu S$.

3.1 ANSWERS :

$$\begin{aligned} h_{ib} = 19.89\Omega \quad h_{ic} &= 4000\Omega \\ h_{rb} = 4.973 * 10^{-4} \quad h_{rc} &= 1 \\ h_{fb} = -0.9950 \quad h_{fc} &= -201 \\ h_{ob} = 1.243 * 10^{-7} S \quad h_{oc} &= 25\mu S \end{aligned}$$

4 Problem 5

The voltages and currents marked are time varying small increments around a Q-point. Calculate the CE, CC and CB y-parameters in terms of the CE h-parameters.



4.1 ANSWERS :

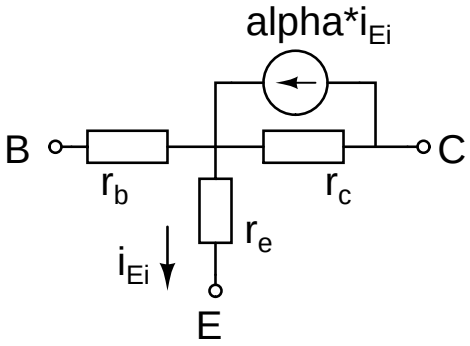
$$\begin{aligned} y_{ie} &= \frac{1}{h_{ie}} \\ y_{re} &= -\frac{h_{re}}{h_{ie}} \\ y_{fe} &= \frac{h_{fe}}{h_{ie}} \\ y_{oe} &= h_{oe} - \frac{h_{re}h_{fe}}{h_{ie}} \end{aligned}$$

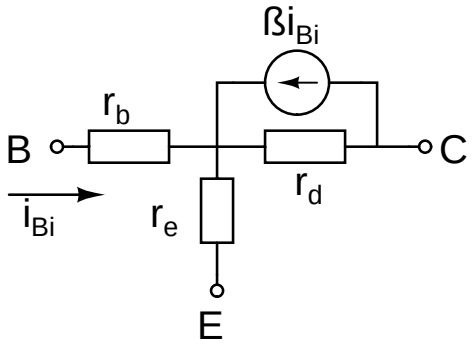
$$\begin{aligned} y_{ib} &= \frac{(1-h_{re})(1+h_{fe})}{h_{ie}} + h_{oe} \\ y_{rb} &= \frac{h_{re}(1+h_{fe})}{h_{ie}} - h_{oe} \\ y_{fb} &= -[\frac{(1-h_{re})h_{fe}}{h_{ie}} + h_{oe}] \\ y_{ob} &= h_{oe} - \frac{h_{re}h_{fe}}{h_{ie}} \end{aligned}$$

$$\begin{aligned} y_{ic} &= \frac{1}{h_{ie}} \\ y_{rc} &= \frac{h_{re}}{h_{ie}} - 1 \\ y_{fc} &= \frac{-(1+h_{fe})}{h_{ie}} \\ y_{oc} &= h_{oe} + \frac{(1-h_{re})(1+h_{fe})}{h_{ie}} \end{aligned}$$

5 Problem 6

Two other equivalent circuits for a transistor are





Currents and voltages shown are small time varying increments around the Q-point. Get h_{ib}, h_{rb}, h_{fb} and h_{ob} in terms of r_e, r_b, r_c and α. Also express r_c and α in terms of r_d and β occuring in the other circuit.

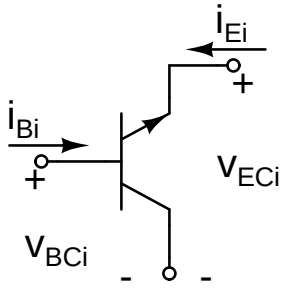
5.1 ANSWERS :

$$\begin{aligned} r_c &= (\beta+1)r_d \quad \alpha = \frac{\beta}{\beta+1} \\ h_{ib} &= r_e + (1-\alpha)\frac{r_b r_c}{r_b + r_c} \\ h_{rb} &= \frac{r_b}{r_b + r_c} \\ h_{ob} &= \frac{1}{r_b + r_c} \end{aligned}$$

6 Problem 7

If the incremental quantities marked on the transistor are very small, they can be expressed as follows:

$$\begin{aligned} v_{BCi} &= h_{ic} i_{Bi} + h_{rc} v_{ECi} \\ i_{Ei} &= h_{fc} i_{Bi} + h_{oc} v_{ECi} \end{aligned}$$



Calculate the CC h-parameters given that r_e, r_b and r_d are 20, 200 and 20000 ohms respectively and that β is 200.

6.1 ANSWERS :

$$\begin{aligned} h_{ic} = 4.216K \quad & h_{rc} = 0.9990 \\ h_{fc} = -2000.799 \quad & h_{oc} = 4.995 * 10^{-5} S \end{aligned}$$

7 Problem 8

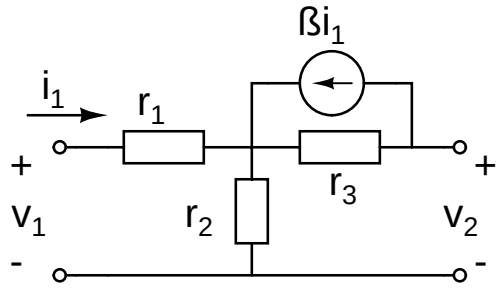
r_e, r_b, r_d and β are 25Ω, 300Ω, $35K\Omega$ and 150 respectively at a particular Q-point. Calculate the CC h-parameters of the transistor that Q-point.

7.1 ANSWERS :

$$\begin{aligned} h_{ic} = 4.0723K \quad & h_{rc} = 0.999286 \\ h_{fc} = -150.892 \quad & h_{oc} = 2.855 * 10^{-5} S \end{aligned}$$

8 Problem 9

Find the Z and Y parameters of the following circuit



$r_1 = 200\Omega$, $r_2 = 20\Omega$, $r_3 = 20K\Omega$ and $\beta = 249$

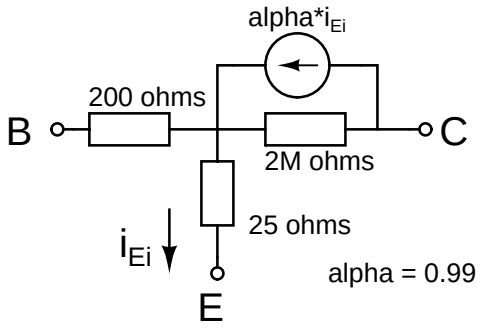
8.1 ANSWERS :

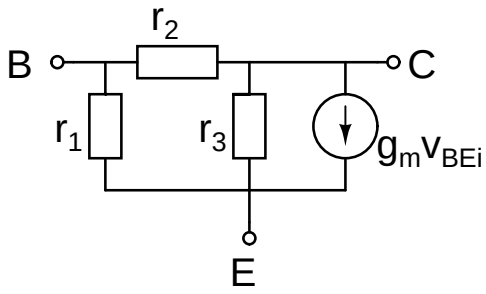
$$\mathbf{Z} = \begin{pmatrix} 220\Omega & 20\Omega \\ -4.97998M\Omega & 20.02K\Omega \end{pmatrix}$$

$$\mathbf{Y} = \begin{pmatrix} 0.1925mS & -0.1923\mu S \\ 47.8826mS & 2.1153\mu S \end{pmatrix}$$

9 Problem 10

The following are the incremental equivalent circuits of the CE transistor for small increments around a Q-point. If both are identical, find r_1, r_2, r_3, and g_m.





9.1 ANSWERS:

$$\begin{aligned} r_1 &= 2.70025K\Omega \\ r_2 &= 2.1602M\Omega \\ r_3 &= 270.025K\Omega \\ g_m &= 36.663mS \end{aligned}$$